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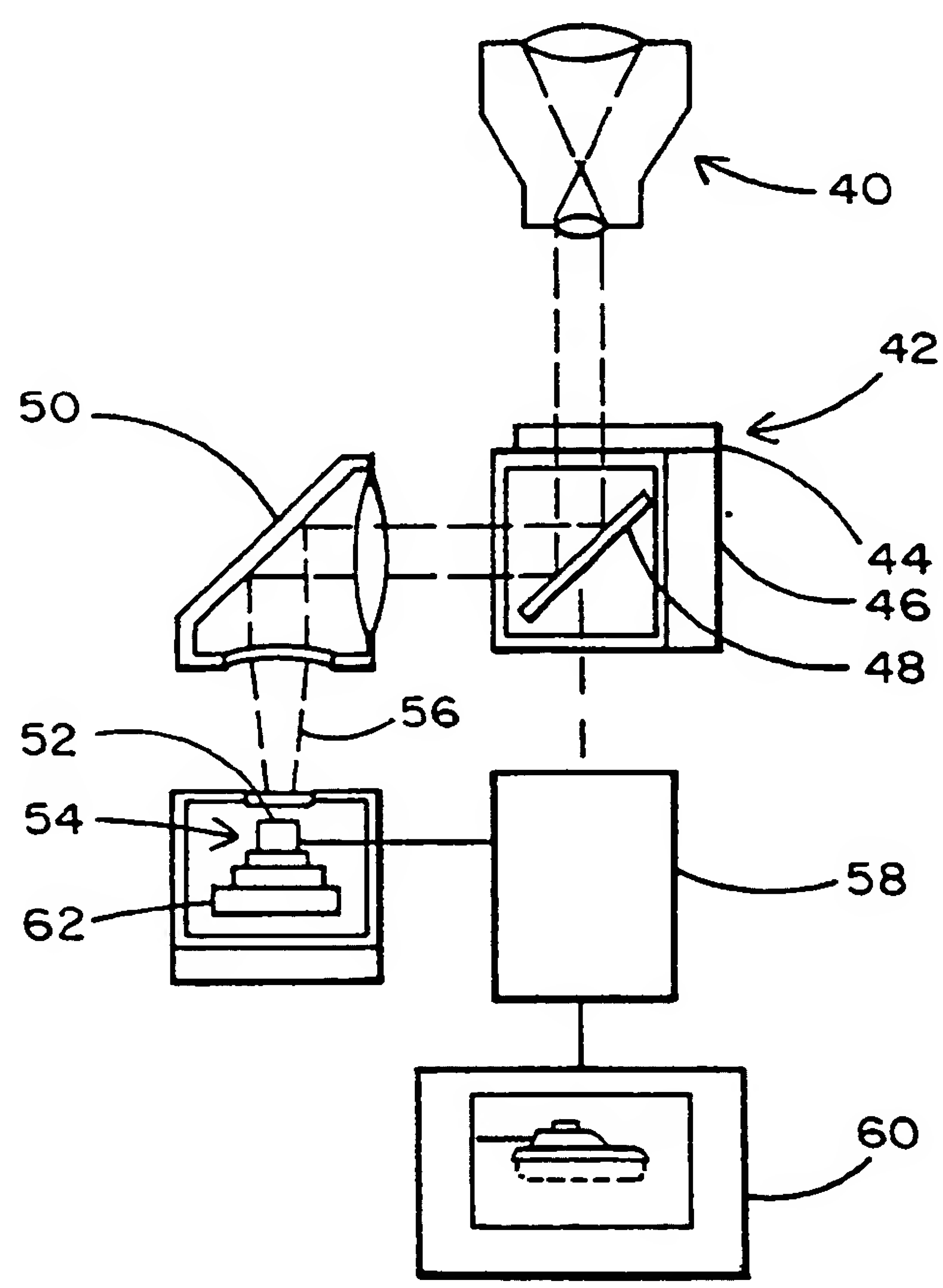
(54) Title: THERMAL IMAGER INCORPORATING SENSOR WITHIN ELECTRONICS MODULE

(57) Abstract

A thermal imaging system in which infrared radiation (56) from the viewed scene is transmitted to a two-dimensional detector array carried on the focal plane (52) of an optical/electronics module (54) which has embedded in it amplifying, filtering and multiplexing circuitry utilizing MOSFET transistors. The module is located inside the cooling device (62). Cooling requirements depend on the alternatives (a) of using detectors responsive to wavelengths in the 3.0 to 5.0 micron range, which require less cooling, or (b) of using detectors responsive to wavelengths in the 8.0 to 12.0 micron range, which require liquid nitrogen cooling. The two-dimensional detector array may be combined with a limited scanning, called "nutation", which causes each detector to view a plurality of pixels in the incoming infrared radiation.



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"Thermal Imager Incorporating Sensor within Electronics Module"

Background of the Invention

This invention relates to the field of thermal imaging, and to the systems commonly known as forward looking infrared (FLIR) systems.

The primary purpose of FLIR systems is night vision. Prior art systems, referred to as Common Module FLIRs (CMFLIR), are designed to use infrared detection to permit an operator to, in effect, "see" and identify objects which would otherwise be invisible. Such a system employs mechanically scanned line array of photo-conductive mercury-cadmium-telluride (MCT) detectors cooled to approximately $77^{o}K$. The term "common module" refers to the requirement that each major component of the system be replaceable by an equivalent module.

In the "Preliminary Common Module Design Handbook" published by Magnavox, the following common module FLIR elements are listed: (1) Detector, comprising an array of 180 vertically oriented elements of Mercury Cadmium Telluride (HgCdTe); (2) IR (infrared) Imager, which directs infrared inputs toward the detector; (3) Scanner, which is a mechanically oscillating mirror sequentially directing infrared inputs onto the linear detector array; (4) Scan and Interlace Electronics, which provides mirror motion drive; (5) Cooler, which maintains the detectors at approximately $77^{o}K$; (6) Preamplifiers, which provide a 70 to 1 amplification of the electronic output signals of the detectors;

(7) Post Amplifiers, which further amplify the detector output signals; (8) LED Display, which converts the amplified detector output signals into visible light, which is collimated by a Visual Collimator module and returned to the reflecting back surface of the scan mirror; and (9) Image Intensifier, which receives the scanned LED display output, intensifies it, and directs it to a biocular eyepiece.

The complexity and costliness of the present FLIR systems is apparent from the extensive number of major components. Also, they have significant performance limitations.

Some of the needs of the prior art Common Module FLIRs are: (a) more producible detector arrays, presently a manufacturing bottleneck; (b) TV display compatibility without the complex electronic interface units [redacted] and maintenance requirements of liquid nitrogen cooling; and (d) reduced number and size of the system components.

The purposes of the present invention are to meet those needs, and, perhaps more importantly, to provide a new FLIR system which will offer the option of either maintaining or improving performance at a greatly reduced cost, or providing much better performance without a cost increase.

Summary of the Invention

The present invention provides a basically altered FLIR system which incorporates a detector module having in a single miniature structure both a focal plane on which are

located a multiplicity of staring detectors and a three-dimensional electronics package which pre-amplifies, filters and multiplexes the electronic signals received from the detectors.

Performance is vastly improved by providing a much greater number of detectors, reducing or eliminating scanning requirements, and locating low noise, high performance electronic processing at the focal plane (inside the detector cooling unit).

The performance improvements permit the alternative choices of (a) using relatively high efficiency detectors to provide a much more sensitive system than prior art systems, or (b) using lower efficiency detectors to provide sensitivity at least equal to that of prior art systems, but at a much lower cost.

Another choice of alternatives is to (a) eliminate entirely the scanning function, thereby removing a complex part of the system, or (b) use limited (and simplified) scanning means to provide a plurality of resolution pixels for each detector.

Brief Description of the Drawings

Figure 1 is a diagrammatic showing of a prior art Common Module FLIR System;

Figure 2 is a diagrammatic showing of the present invention, in which applicants' detector module replaces several of the components in the prior art system;

Figure 3 is a partly-sectional showing of a much

simplified radiation input portion of the system of Figure 2;

Figure 4 is an isometric close-up of the detector module and its cooling structure used in Figs. 2 and 3;

Figure 5 is a partly exploded isometric view of the stacked circuit-carrying layers which constitute the detector module;

Figure 6 is an electronic block diagram of the layer-carried circuitry associated with each detector mounted on the module;

Figure 7 is a schematic of a preamplifier circuit suitable for the circuitry of Figure 6;

Figure 8 is a schematic illustration of the switched capacitance network used as a resistance-equivalent in the adaptive bandpass filter of Figure 6;

[redacted] suitable for the circuitry of Figure 6;

Figure 10 shows an optical intake system for directing radiation to the detector array, which system includes means (referred to as a "nutator") for causing limited scanning motion of the radiation directed to each detector;

Figure 11 is an isometric view showing the nutating mirror element of Figure 10;

Figures 12A and 12B are cross-sections taken through the structure of Figure 11 along the two pivot axes of the nutating mirror;

Figure 13 shows a different embodiment of an optical

intake system in which the nutation is accomplished by a refracting element rather than a reflecting element; and

Figures 14 and 15 show two possible scanning patterns which might be used in nutator scanning, including a pattern in which the same radiation is directed to more than one detector, for comparison and calibration purposes.

Detailed Description of Specific Embodiments

Figure 1 shows a typical Common Module FLIR system. Thermal (IR) radiation from the viewed scene is received by an optical module 12, having an afocal magnifying lens. A collimated beam 14 from module 12 impinges on a mirror 16 incorporated in a scanner module 18. Mirror 16 reflects IR energy to an imaging module 20, which focuses it on a detector module 22. The detector comprises a vertically-oriented line array of detector elements, which are formed of mercury cadmium telluride (HgCdTe, hereafter "MCT").

Because a line array detector module is used, it is necessary to scan across the viewed scene, in order to cause energy from successive segments of the scene to impinge seriatim on the detectors. This is accomplished by causing oscillation of mirror 16 about its axis. The mirror is driven, by a suitable motor, through a scan angle up to 10° (5° to each side of center).

The electronic signals output by the scanned detector array 22 are directed first to a pre-amplifier module 24, and then to a post-amplifier module 26. The amplified signals are then conducted to an LED module 28, which has an

LED element corresponding to each detector element. Visible light from the LED module is collimated by a visual collimator module 30; and the collimated beam 32 is passed to the back of scan mirror 16 (which also is a reflecting surface).

The scanning movement of mirror 16 causes the visible light to image a visual representation of the infrared scene on the face of a light intensifier module 34, which permits viewing by an observer through a biocular eye-piece 36.

An important and expensive module is the cooler, which is indicated at 38. The MCT detectors need to be cooled to approximately 77°K. Only the detectors are cooled; the electronics are all in a relatively "warm" environment.

The invention of the present application is a thermal imaging system (FLIR) in which: (a) a two-dimensional array [redacted] detector array is on one surface of a module which contains electronics for pre-amplifying, filtering and multiplexing the detector output signals, all located in the cooler.

Other FLIR systems are being developed having two-dimensional detector arrays, rather than a scanned linear array. As pointed out in a descriptive paper: "Staring arrays are being considered for many of the next generation IR systems because of the potential of increased performance with less mechanical complexity. Longer integration time of staring arrays offers a sensitivity increase when compared to scanned systems. Elimination of mechanical scanning gives size, cost and reliability advantages to staring

arrays. This is especially true in missile seekers with size constraints. These advantages also apply to threat detection applications in which many arrays are required to continuously cover the total 4 steradians field of regard."

Except for the present invention, the proposed two-dimensional arrays of staring detectors for FLIR systems are planar arrays, either hybrid or monolithic, which rely on non-focal-plane electronics; i.e., the detector output signals are conducted to electronic processing circuitry located away from the detector plane. The advantages of the present invention over planar array systems will be discussed in detail below.

Figure 2 shows a plan view diagram of one embodiment of a FLIR system incorporating the present invention. An optical module 40 directs a collimated IR beam to a module 42, which includes a chopper assembly 44 driven by motor 46, and a fixed (non-scanning) mirror 48. The collimated beam is reflected by mirror 48 to an imaging module 50.

The incoming IR energy is directed by imaging module 50 to a two-dimensional detector array on the focal plane 52 of a detector/electronics module 54. The IR beam 56, which impinges on focal plane 52, covers the entire area of the focal plane (instead of being focused on a single detector, as in the system of Figure 1). The detector array may include any desired number of detectors, an array of 128 X 128 being an exemplary choice.

The detector/electronics module 54 includes electronics

for independently pre-amplifying and filtering the electronic information from each detector, and then multiplexing the detector signals. This multiplexed output is conducted to a video signal generator 58, whose output is conducted to a video display 60.

The detector/electronics module 54 may be mounted in a cooler 62, if efficient detector operation requires cooling. A major advantage of the present invention is its capability of providing substantial electronic processing at the focal plane (inside the cooler). As will be explained in detail below, this is possible because of the unusually low power dissipation of the electronic circuitry in module 54.

It is apparent that the system of Figure 2 has substantially simplified the system of Figure 1. However, the present invention permits much further simplification [redacted] was designed for maximum compatibility with the Common Module FLIRs which are currently in widespread use.

In the system of Figure 3, IR energy from the viewed scene is received by lens 64, and directed through suitable optics 66 and a chopper 68 to a two-dimensional focal plane 70 on a detector/electronics module 72. The module 72 is supported in a multi-stage thermoelectric cooler 74, and has its electronic output signals conducted to a video signal generator via connectors 76.

The purpose of chopper 44 in Figure 2 and of chopper 68 in Figure 3 is to provide a DC reference value against which the detector signals are compared; i.e., the choppers are

needed to briefly cut off the radiation from the viewed scene and to look, instead, at a surface which provides information for calibration purposes. This calibration function in the prior art scanning FLIR of Figure 1 is accomplished by continuing the scanning sweep past the edges of the viewed scene.

Figure 4 shows an enlarged isometric view of the cooler 74 and the detector/electronics module 72. The focal plane 70, which may, for example, contain an array of 128 X 128 detectors, is one surface of module 72, which comprises a multiplicity of layers 78 extending in planes perpendicular to focal plane 70. These layers each carry electronic circuitry, which will be detailed below. A plurality of leads 80 are provided, which are electrically connected to the bottom, or back plane, of module 72, for the purpose of inputting control signals to the module, and outputting detector-initiated signals from the module. The module is mounted atop the cooling platform of multi-stage thermo-electric cooler 74, and is further protected from heat by radiation shields 82, which are cooled by the cooler 74, and which prevent spurious energy from reaching module 72.

The three-dimensional detector/electronics modules 54 in Figure 2, and 72 in Figure 3, may be similar to those disclosed in U.S.S.N. 187,787, filed 9/16/80, and in its continuation U.S.S.N. 572,802, filed 1/23/84, both assigned to the assignee of this application. As shown in Figure 5, such a module comprises a stack of thin layers 84, each

carrying circuitry which performs pre-amplifying, filtering and multiplexing functions on the individual photo-detector output signals. Preferably the layers 84 are semiconductor chips having integrated circuits (IC) formed thereon. The chips are secured together to form the module, and each has a large number of closely spaced electrical leads at the focal plane, which has an array of detectors 86. Each detector is independently in electrical contact with one of the closely spaced electrical leads provided by the circuitry on the chips.

Backplane wiring 88 is used to connect the circuitry on the stacked chips with the external electrical leads 80 (Figure 4).

Figure 6 exemplifies the general layout of circuitry connected to each detector. If a [redacted], each chip (or layer) 84 will carry 128 such circuits, and 128 chips (or layers) 84 will be stacked and bonded together. As shown, each detector 90 has its output connected to a preamplifier 92. Each preamplifier feeds its output signal to an individual adaptive bandpass filter 94, which selects the desired band of frequencies to be processed. The post-filter signal is input to a multiplexer 96, which comprises parallel input branches from each of the separate detector circuits, and a control circuit which causes sequencing of the multiplexed output signals conducted off the chip.

The preamplifier 92 may be similar to that disclosed and claimed in common assignee application U.S.S.N. 558,099,

filed December 5, 1983; and the multiplexer 96 may be similar to that disclosed and claimed in common assignee U.S. Patent No. 4,490,626, issued December 25, 1984 on Application No. 403,004, filed July 29, 1982. The circuit of Figure 6 is designed for the use of photo-voltaic detectors. If photo-conductive detectors are used, an exterior current source 98 (shown in phantom) is included.

All of the "focal plane" circuitry, i.e., comprising the separate preamplifiers, separate filters and multiplexing circuitry, is located inside the cooled container, the reduced temperature of which is required for detector effectiveness.

The transistors used in the focal plane circuitry located on the stacked chips are preferably MOSFETS, because of their ability to operate under cryogenic conditions, and because of major advantages which they bring to the problems addressed in developing suitable "on-focal-plane" circuitry. A fundamental problem is the requirement for low power operation, because power dissipation must be minimal.

As a means of minimizing power dissipation, the preamplifier 92 is operated in the "weak inversion" mode (also referred to as "sub-threshold" or "current-starved"). The importance of this functional aspect is discussed in detail in U.S.S.N. 558,099. In that application, it is explained that the disclosed preamplifier--an operational amplifier held in the weak inversion range-- meets the severe requirements, including space limitations, low power limitations,

high gain requirements, and variable gain adjustability. The disclosure of that application is incorporated by reference in the present description.

Figure 7 corresponds to Figure 2 of U.S.S.N. 558,009, but its description omits much of the specific description included in the prior application. In Figure 7, the pre-amplifier has a differential amplifier portion comprising six MOSFET transistors: a differential pair 104 and 106; a cascode pair 108 and 110; and a current mirror pair 112 and 114. Transistor 104 has its gate connected to the detector signal; and its matched transistor 106 has its gate connected to ground.

The sources of transistors 104 and 106 are both connected to a constant current source 116. Another constant current source [redacted]tor 120, which provides the output signal from the preamplifier to the filter 94. The source follower transistor 120 has its source-to-drain current flowing between the constant current source 118 and the negative bias voltage 122. The positive bias voltage 124 is applied at one side of the two constant current sources 116 and 118.

The feedback resistance of the operational amplifier, which is shown diagrammatically at 126 in Figure 6, is preferably provided by a switched capacitance network (as shown in Figure 7), which comprises MOSFET switching transistors 128 and 130, capacitor 132, and clock-controlled inputs at gates 134 and 136. By changing the frequency of the switching network, the equivalent resistance value can

be varied for optimal results. In other words, the preamplifier gain is variable on a real time basis.

The amplified signal from each detector is fed into the adaptive bandpass filter 94, where the output signal is limited to the desired range of frequencies. The filter 94 couples the detector to the multiplexer and performs the function of real time clutter rejection, which is very important in preventing unwanted extraneous signals from entering the multiplexer, and thus from entering subsequent post-processing where they must be removed in a more complicated process. The bandpass filter is implemented using switched capacitors in place of resistive elements. Figure 8 shows an individual resistance-equivalent switched capacitance network comprising two MOSFET transistors 138 and 140, which act as frequency-controlled switches, and a capacitor 142. Use in the filter of CMOS switching elements, which are compatible with the other on-chip transistors, simplifies filter fabrication and provides a high degree of uniformity from one filter to another, since the equivalent resistance value is dependent on the size of the capacitors. MOSFET capacitors will vary due to geometry differences, but these can be held to a very tight tolerance. A second advantage of switched-capacitor implementation is that, by adjusting the clock frequency, the equivalent resistor can be altered in value. This principle allows the bandpass filter to be varied in frequency by adjusting the clocking rate of the switches.

The third, and final, on-chip segment of electronic circuitry is the multiplexer. Figure 9, which shows a desirable multiplexer circuit, is substantially identical to Figure 3 of U.S. Patent No. 4,490,626. Because the multiplexer circuit is discussed in detail in that patent, that disclosure is incorporated herein by reference, and the description of the circuit here will be relatively brief.

Figure 9 shows three parallel branches of the multiplexer, each of which contains two MOSFET transistors. A MOSFET 150 in each branch is an amplifier of the analog signal from its respective detector. A MOSFET 152 in each branch acts as a switch which, when enabled, connects the MOSFET 150 in the same branch to a multiplexer output line 154.

Each MOSFET 150 receives [redacted] from its respective detector. Significantly, its output analog signal is the source-to-drain current flow, which varies proportionally to the input voltage, the source of each MOSFET 150 being connected to the common source voltage, and the drain of each MOSFET 150 being connected to the drain of the respective switch MOSFET 152.

Each switch MOSFET 152 has its gate connected to its respective line 156 from the logic circuit; and its source connected to the common multiplexer output line 154. Under the control of the logic circuit, the switch MOSFETs 152 are normally disabled, allowing no current flow through the respective amplifier MOSFETs 150. When a "trigger in"

signal is received by the logic circuit, it first sends a voltage signal on the line 156 designated V(SX-O), causing the switch MOSFET 152 designated Q(B-O) to turn on. A current analog output signal is thereupon permitted to flow in the amplifier 150 designated Q(A-O), which signal is proportional to, but amplified to a much higher power than, the input signal designated V(IN-O); and the amplified current output signal from Q(A-O) is transmitted through switch Q(B-O) to the multiplexer output line.

The logic circuit then turns off the signal on the line V(SX-O), and sends a voltage signal on the next line designated V(SX-1) to turn on the next switch 152 designated Q(B-1). This permits an amplified analog current signal to flow in the amplifier 150 designated Q(A-1), in the same branch as switch Q(B-1); and permits that signal to pass to the multiplexer output line. This process is continued until all detector-amplifier combinations have sent their output signals in the desired order to the output line.

Each switch 152 may be controlled by a typical CMOS switch in the logic system, one of which is shown at the right side of Figure 9 connected to V(SX-N). Each CMOS logic switch comprises a P-channel MOSFET 160 having its source connected to V(DD), and an N-channel MOSFET 162 having its source connected to V(SS). [Values of the source voltages may be approximately 5V at V(DD) and approximately 0V at V(SS)]. The gates of the respective MOSFETs 160 and 162 are both connected to the logic circuitry; and the

drains of the respective MOSFETs 160 and 162 are both connected to the gate of on of the switch MOSFETs 152.

As explained in U.S.S.N. 403,004, the multiplexer circuitry has important benefits, including (a) minimal power dissipation because no current flows in either transistor of a disabled branch, and (b) minimal cross-talk between branches because analog current signals are output instead of analog voltage signals.

The use in an FLIR system of the stacked chips which have substantial electronic circuitry located at the focal plane, and which are located inside the cooling element, provides important synergistic effects. It makes detector performance much less critical, because electronics gain reduces the "work" required from the detectors. The focal plane pre-amplifier allows each detector to have the desired DC bias voltage, which [redacted] multiplexing at the focal plane complete the electronic processing which is important to accomplish before the signals are routed to external circuitry. In other words, the number of leads exiting the module 72 is minimized; but all processing needed on each separate detector signal has been accomplished prior to multiplexing.

Another advantage is the availability of random access readout, which is not possible with a line array. This permits the present system to provide a TV-display output with much simpler electronics. The common module FLIR system requires very complicated re-formatting if a TV-display output is required.

Common Modular FLIR systems are designed to be operated in the spectral band from 8.0 to 12.0 microns, using MCT detectors in the photo-conductive mode. However, attractive tradeoffs may be offered by FLIR systems operating in th 3.0 to 5.0 micron spectral band. The present invention may provide, in comparison with prior art systems, either a less costly system operating in the mid IR range (3.0 to 5.0), or a higher performance system operating in the far IR range (8.0 to 12.0).

If the detectors used in the present system are photo-voltaic MCT detectors, operating in the 8.0 to 12.0 micron wavelength range, the system performance will greatly exceed that of the existing common module FLIR systems. It will have much higher sensitivity, better image quality, reduced number of components, lower weight, lower power requirements, etc.

On the other hand, the advantages of the present system can be used to permit incorporation of lower performance detectors, greatly reducing cost, without sacrificing system performance. The primary source of cost reduction is eliminating the need for the extreme cooling required by MCT detectors. For example, with the present system, it is feasible to use lead selenide (Pb Se) detectors, operating in the 3.0 to 5.0 micron wavelength range, which require cooling only to 200°K. MCT detectors require cooling to 77°K, which necessitates the use of liquid nitrogen. Liquid nitrogen coolers are expensive, heavy, hard to maintain, and have high power requirements which need heavy battery packs

having limited operating time between replacements.

As previously stated, the use of a two-dimensional array offers a major sensitivity improvement over a scanned line array, because of the longer integration time. The quantitative benefit is approximately the square root of the ratio of the numbers of detectors in the respective arrays. For example, in comparing a two-dimensional array of 128 x 128 detectors to a line array of 128 detectors, the ratio of the number of detectors in the former to the number of detectors in the latter is 128 to 1. The performance gain of the two-dimensional array is approximately represented by the square root of 128. So the improvement is greater than an order of magnitude.

One potential limitation of the present invention relates to the fineness of [redacted] by numerals 54 and 72, the present center-to-center distance between detectors is .004 in. In the line array systems, a center spacing of .002 in. has been used.

The modules 54 and 72 can be considered as having an X-axis which is parallel to the planes of the stacked layers 78 (Figure 4), and a Y-axis which is perpendicular to the planes of the layers. Because the Y-axis spacing of detector leads is controlled by the thickness of the respective layers, it requires extreme manufacturing accuracy and care to reduce the Y-axis center spacing of the leads.

In order to enhance resolution in the present system, a limited amount of scanning may be introduced. For example, by using each detector to view four points, an array of 128 x 128 detectors on .004 in. centers can provide an array of 256 x 256 pixels on .002 in. centers. This compromise sacrifices some of the performance advantage due to the integration effect of staring sensors, and also some of the advantage of eliminating mechanical scanning. However, there remains a substantial performance benefit; and the limited scanning can be accomplished by a much simpler, less expensive and more reliable mechanism than that required in line array systems.

Figure 10 illustrates a limited scanning feature, which is referred to as "nutation", incorporated in the system of the present invention. Incoming radiation from the viewed scene (at left in the figure) passes through an optical module 170, and is reflected toward the detector/electronics module 72 by a mirror 172. A chopper blade 174 is caused to rotate across the path of radiation focused on the detector focal plane 70 of module 72. The mirror 172 is so arranged that it has a limited scanning motion. For this purpose it may be pivotally movable (for very small distances) about two pivot axes, which are at right angles to one another. It is desired to have the mirror move in sequence to a plurality of fixed positions; and spend as much time as possible in a "staring" mode in each of those positions. If each cycle of motion of the mirror has four fixed data integrating positions, the portion of time available for

data-integration is about seven-eights of the time cycle. In other words, if the time cycle of nutation from starting point back to starting point is assumed to be 33 ms., the total motion time required (which is not available for detector sensing input) is approximately 4 ms., leaving 29 ms. for detector sensing input. The mirror should be stationary during each detector input period, in order to avoid image blurring.

Figures 11, 12A and 12B show a structure suitable for causing nutating motion of mirror 172. The mirror is pivotally movable both on axis X-X and on axis Y-Y. It is carried by an inner gimbal ring 176, which is pivoted on the Y-axis (as shown in Figure 12A), and which in turn is carried by an outer gimbal ring 178. The outer gimbal ring 178 is pivoted on the [redacted] has arms 179 at opposite ends of the X-axis, each of which is connected to a supporting element 180 by a pair of flex pivots 181. The inner gimbal ring 176 has arms 182 at opposite ends of the Y-axis, each of which is connected to the outer gimbal ring 178 by a pair of flex pivots 183. The supporting elements 180 are carried by a mounting plate 184 which is retained in a fixed position in the structure of Figure 10, thereby locating the entire nutator sub-assembly in the desired position.

As shown in both Figures 12A and 12B, a preferred means of causing pivotal motion of mirror 172 is a piezo-electric element, which acts as a voltage-to-pressure transducer.

Such a piezo-electric element is shown at 190 in Figure 12A and at 192 in Figure 12B. Applying a direct electric field across either of the piezo-electric elements 190 or 192 causes it to flex in one direction or the other, depending on the polarity of the electric field. When voltage of one polarity is applied to piezo-electric element 190 (Figure 12A), it moves the inner gimbal ring 176 into engagement with a stop member 194, which has a tapered engaging portion 196 at the end of a threaded portion 198, thus permitting adjustment of the stop-engaging position of the mirror. A similar stop member 194 is located at the opposite end of the inner gimbal ring 176, and is engaged by ring 176 when the polarity of the voltage across piezo-electric element 190 is reversed, causing element 190 to flex in the opposite direction. The total motion caused by flexure of the element 190 is only about 1 mil.

One end of element 190 is secured to the inner gimbal 176 by a bracket 200, and its other end is secured to a pivoted arm 202, the position of which may be adjusted by a screw 204, thereby equalizing the flexing motion required in opposite directions.

As shown in Figure 12B, the same arrangement may be used in controlling the pivotal movement of the outer gimbal ring 178, moving it either into engagement with the stop member 194 at the right side of the gimbal ring, or into engagement with a stop member (not shown) at the left side of the gimbal ring.

Since each of the gimbal rings 176 and 178 has two

alternating stop-engaging positions, the mirror 172 has four fixed signal-viewing positions. By using a single detector to sense radiation from four positions, the available number of pixels per detector has been quadrupled. This has been accomplished with a very slight amount of accurately-controllable scanning motion of the mirror.

Figure 13 shows another mean of causing the nutation scanning effect. Whereas Figures 10-12 use a reflecting mirror as the scanning element, the structure shown in Figure 13 uses a refractive element, which is a prism 210. Its motion may be caused by an annular electric motor 212 moving a cam to cause sequential relocation of the element 210 at each of the desired positions. The length of motion required by a refractive nutating prism is greater than that required [redacted] piezo-electric elements are not considered suitable for the mechanical nutator of Figure 13. Figure 13 shows an optical module 170a, a chopper 174a, and the detector focal plane 70 on the surface of optical/electronic module 72, which is mounted inside a cooling unit.

Using the limited scanning motion, which has been referred to as "nutation", provides innumerable possibilities for performance enhancement of the thermal imager system. Figures 14 and 15 illustrate diagrammatically just two of the possibilities.

In Figure 14, it is assumed that each of a plurality of detectors 220 extends 2 mils in each direction, and that the

detector centers are spaced 4 mils apart in both the X-axis (horizontal) and Y-axis (vertical). Although the detectors are stationary during nutation, while the scene viewed by each detector is moved by the nutator, the resulting scan can be diagrammatically illustrated by plotting imaginary detector movement. Figure 14 illustrates the use of four spaced samples per frame. The pixel center is assumed to start by viewing at point A, first move on X-axis to view at point B, then move on Y-axis to view at point C, then move on X-axis to view at point D, and finally move on Y-axis back to view at point A. This sequence is repeated continuously. The result is that detectors having center-to-center spacings of 4 mils can provide center-to-center pixel resolution of 2 mils. Assuming the square root of 128 as the sensitivity (performance) advantage of the two-dimensional detector mosaic over the line array, the nutation scanning has given up approximately one-half of that advantage, because the frequency bandwidth must be increased by four to allow for four separate frames. This results in a reduction in performance by the square root of four compared to the completely staring case.

Figure 15 illustrates an interesting possibility, which has several potential advantages. First, it requires nutating motion in one direction only (oscillation), i.e., around one axis. Second, it reduces the number of required stopping points. Third, it causes viewing of a given portion of the scene by more than one detector, thereby enhancing uniformity; i.e., relative detector outputs, or gains, can

be electronically adjusted to provide uniform detector response. Fourth, it is particularly compatible with the stacked layer construction of module 72, because it provides increased resolution in one axis. The latter advantage refers to the fact that it is much easier to reduce center-to-center detector spacing along the X-axis, where the electrical leads lie along a single layer surface, than to reduce center-to-center detector spacing along the Y-axis, where the electrical leads are separated by the thicknesses of the stacked layers.

Figure 15 illustrates the use of three samples per frame, one of which involves a second detector. The pixel center is assumed to start by viewing at point A on detector 220a, first move to a second viewing point B, and then move [redacted] the scanner can be returned to point A for repetition of the sequence. Because each detector 220a and 220b has viewed a common pixel, their outputs can be calibrated and adjusted to improve uniformity. This feature can be expanded by combining more than two detectors in the same frame, without eliminating the advantages of (a) simplified mechanical scanning structure, and (b) increased sensitivity because of available detector "staring" time.

From the foregoing description, it will be apparent that the apparatus embodiments disclosed in this application will provide the significant functional benefits summarized in the introductory portion of the specification.

The following claims are intended not only to cover the specific embodiments disclosed, but also to cover the inventive concepts explained herein with the maximum breadth and comprehensiveness permitted by the prior art.

What Is Claimed Is:

1. A thermal imager, for detection of non-visible infrared radiation from objects, including:

an optical input structure for receiving and focusing infrared radiation;

a detector module having (a) a focal plane surface comprising a two-dimensional array of detectors which convert radiation signals from the optical input structure into electronic information, and (b) signal-processing electronics embedded in the body of the module which amplify, filter and multiplex the electronic signals supplied by the detectors; and

a video signal generator actuated by the multiplexed output signals from the detector module to [redacted]

2. The thermal imager of claim 1 which also comprises:

a cooling element, within which the detector module is located, having means for maintaining the cryogenic temperature needed for optimum detector sensitivity.

3. The thermal imager of claim 1 wherein the signal-processing electronics in the detector module comprise transistors all of which are MOSFET devices.

4. The thermal imager of claim 3 wherein the amplification portion of the signal-processing electronics comprises an operational amplifier operated in the weak-inversion mode, thereby minimizing power dissipation

requirements and increasing the signal amplification ratio.

5. The thermal imager of claim 3 wherein the filtering portion of the signal-processing electronics comprises switched capacitance resistance-equivalents controlled by MOSFET switches, thereby permitting adjustment of the output bandwidth by frequency variations, in order to accommodate the bandwith responsivity of the detectors.

6. The thermal imager of claim 3 wherein the multiplexer portion of the signal-processing electronics comprises branches each combining a MOSFET amplifier transistor which has a variable-current output signal with a MOSFET switch which prevents current flow in the branch except when enabled.

7. The thermal imager of claim 5 wherein:

the detectors are operative to detect signals in the approximate wavelength range of 3.0 to 5.0 microns.

8. The thermal imager of claim 5 wherein:

the detectors are operative to detect signals in the approximate wavelength range of 8.0 to 12.0 microns.

9. The thermal imager of claim 7 wherein:

the detectors are formed of lead selenide material and operate in the photo-conductive mode.

10. The thermal imager of claim 8 wherein:

the detectors are formed of mercury cadmium telluride

material and operate in the photo-voltaic mode.

11. A thermal imager, for detection of non-visible infrared radiation from objects, including:

an optical input structure for receiving and focusing incoming infrared radiation;

a two-dimensional detector array which converts the incoming infrared radiation into electronic signals;

a limited mechanical scanning device which causes each detector to view a plurality of pixels in the incoming infrared radiation; and

a video signal generator actuated by the output electronic signals from the detector array.

12. The thermal imager of claim 11 which also comprises:

[redacted] having (a) a focal plane surface carrying the two-dimensional detector array, and (b) signal-processing electronics embedded in the body of the module which amplify, filter and multiplex the electronic signals supplied by the detectors.

13. The thermal imager of claim 11 wherein the mechanical scanning device has limited pivotal motion around two axes, which are at right angles to one another.

14. The thermal imager of claim 13 wherein the mechanical scanning device causes each detector to view at least four pixels in the incoming infrared radiation.

15. The thermal imager of claim 11 wherein each detector views at least two pixels in the incoming radiation, and at least two detectors view the same pixel.

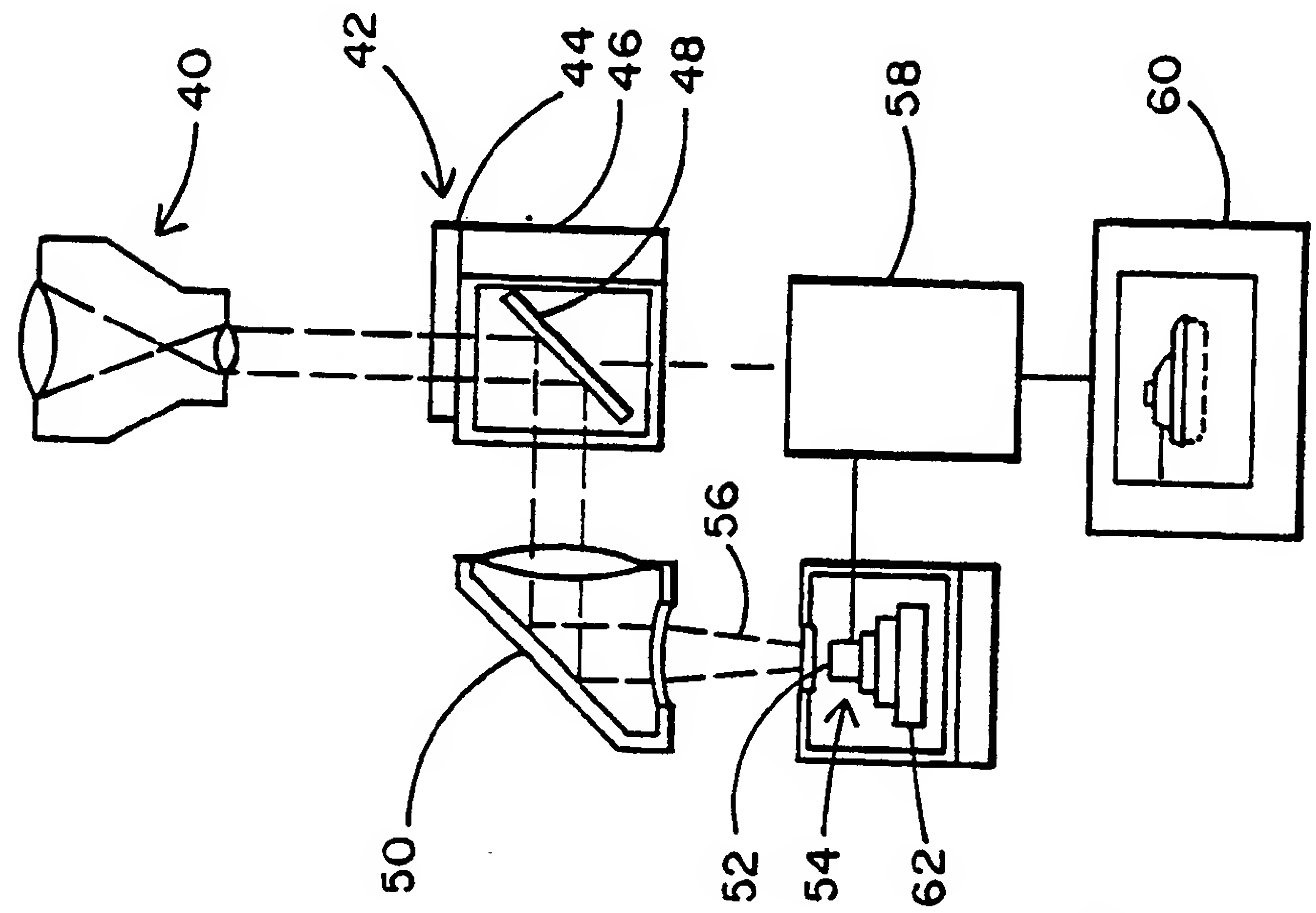


FIG. 2

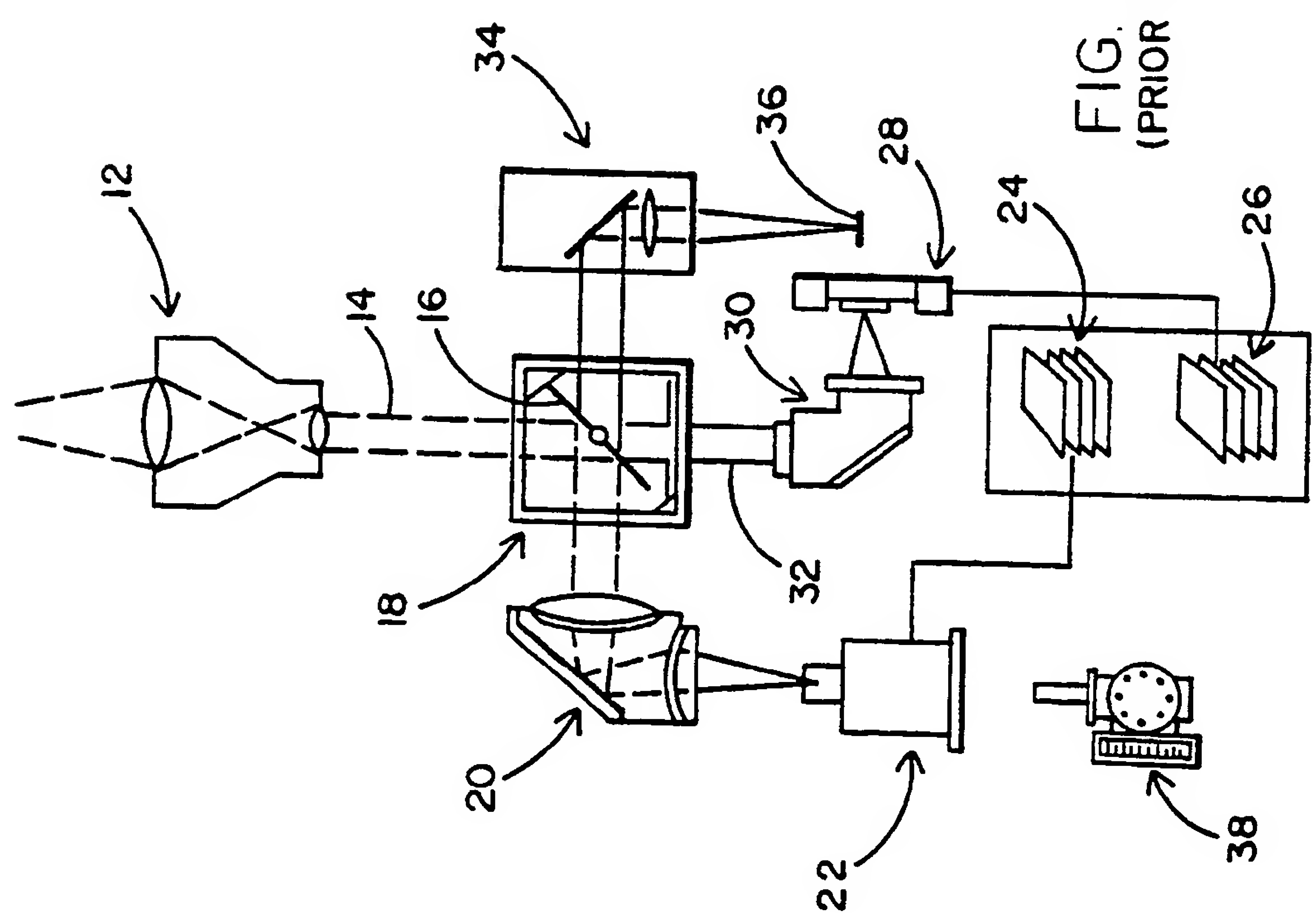


FIG. 1
(PRIOR ART)

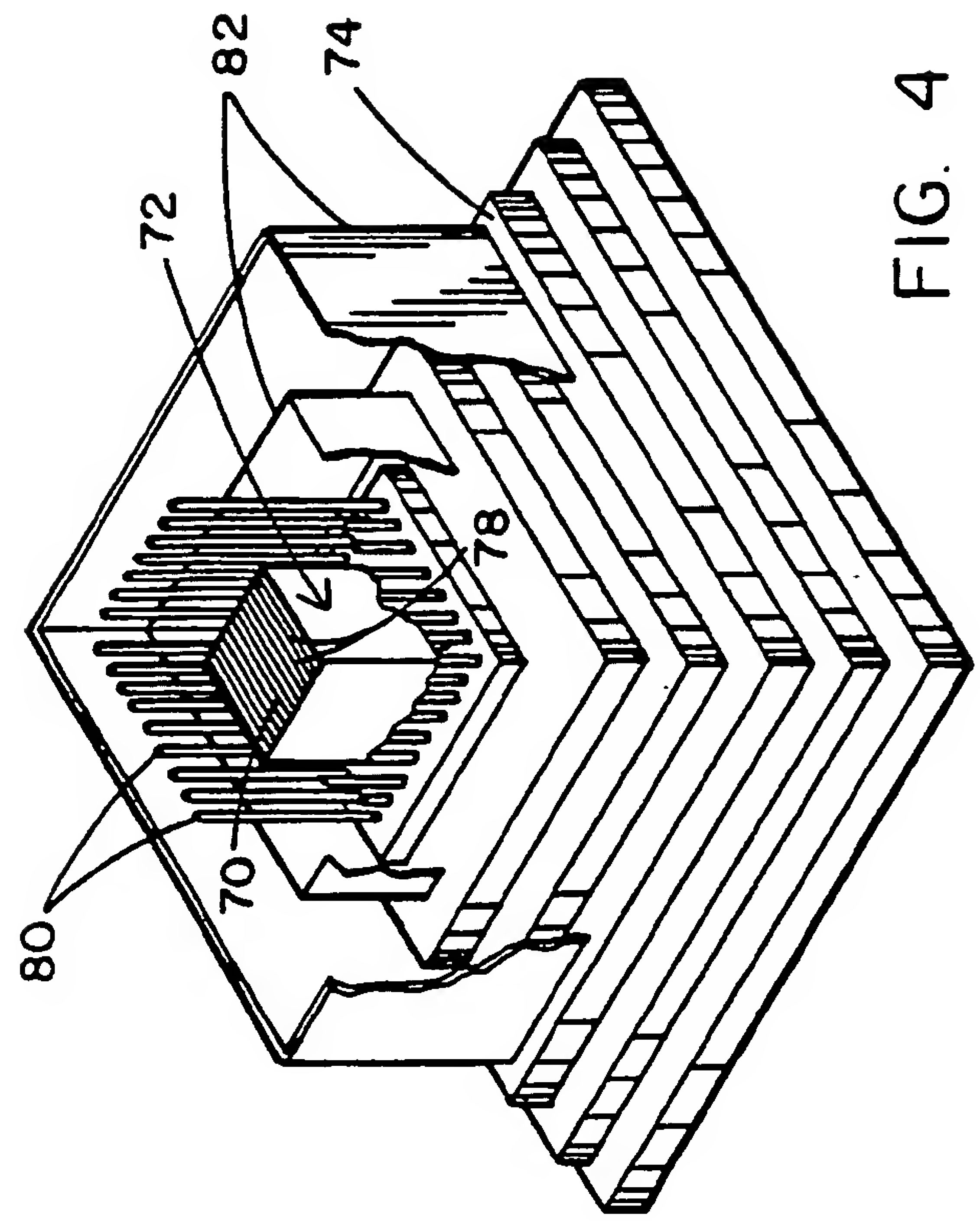


FIG. 4

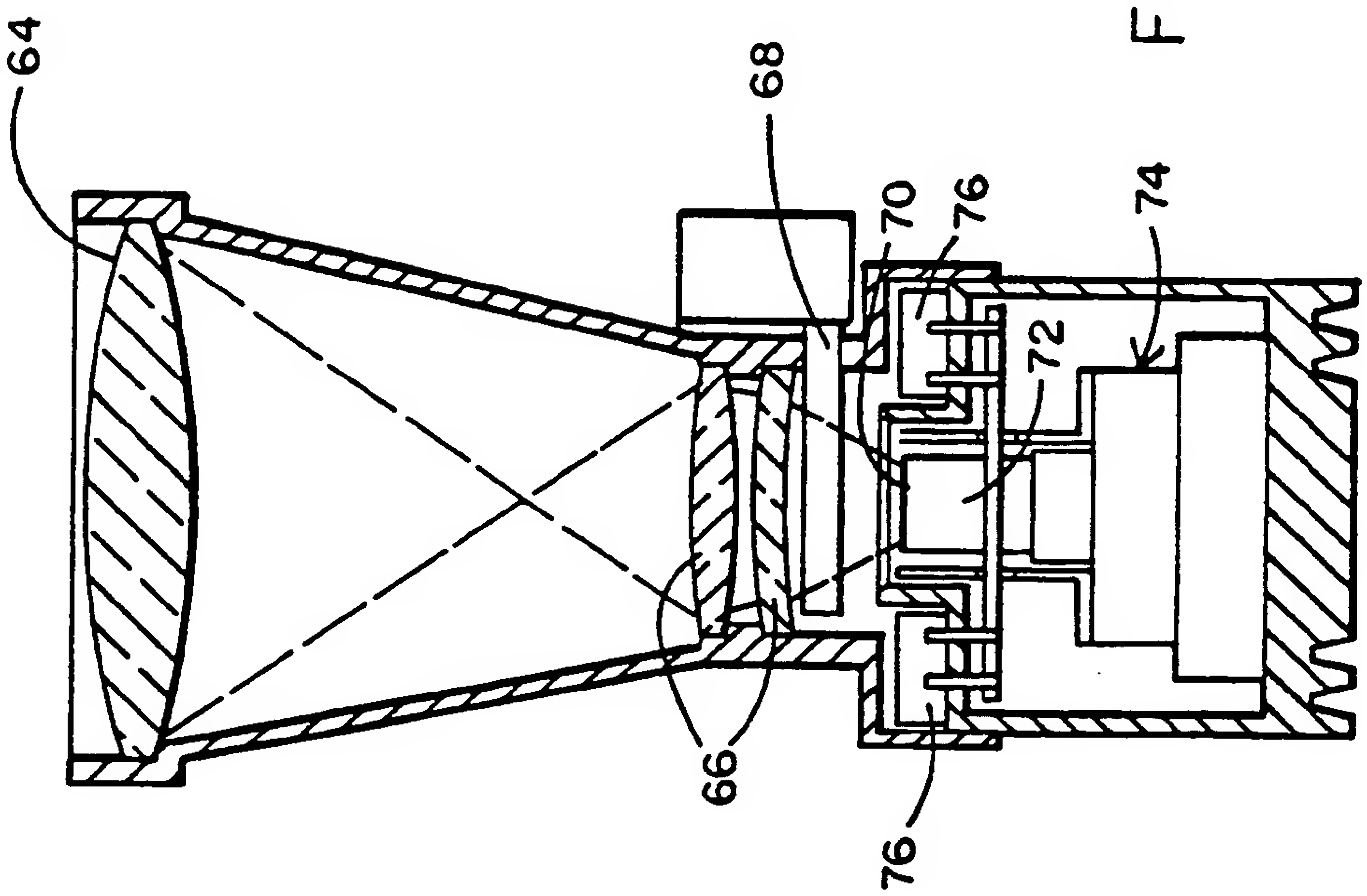


FIG. 3

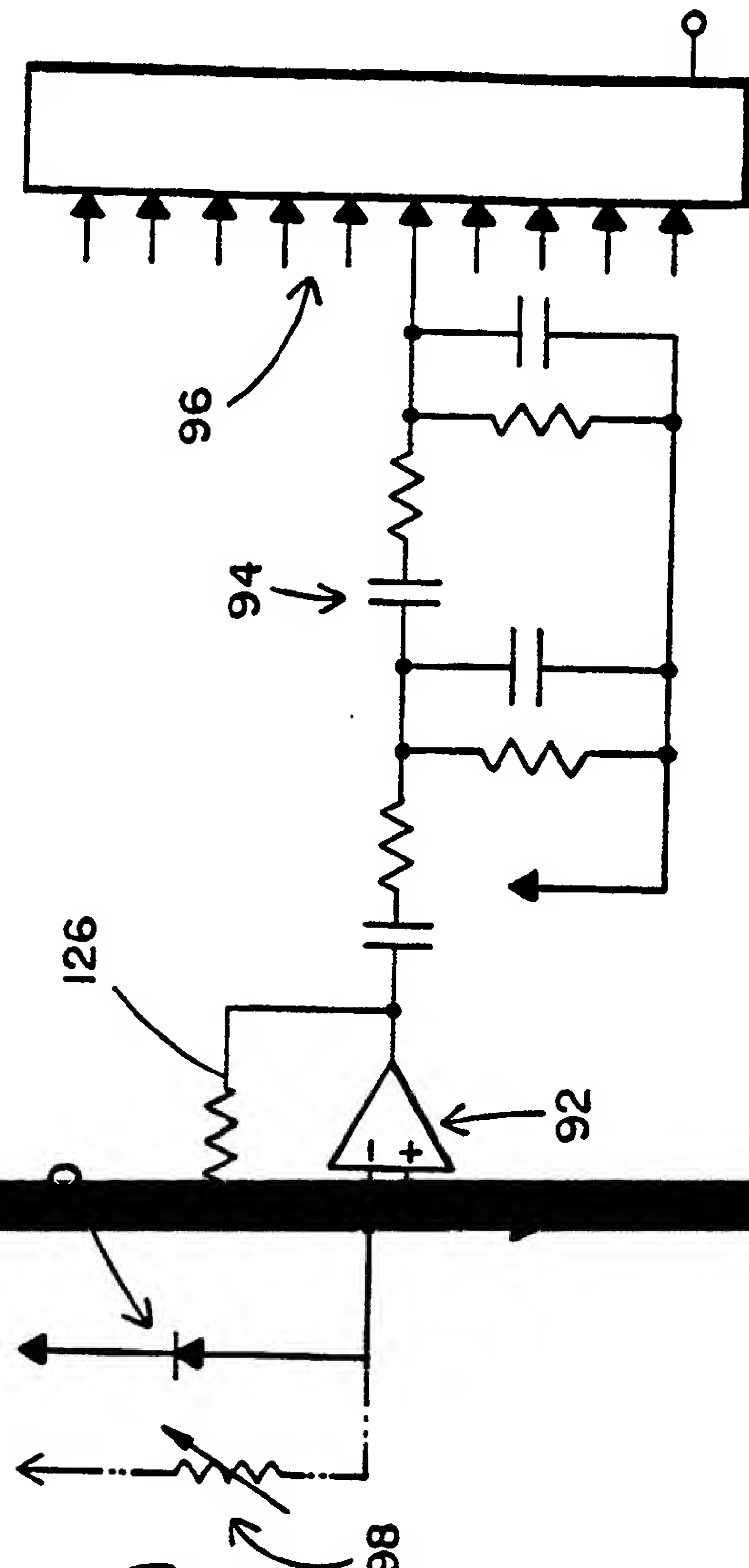


FIG.

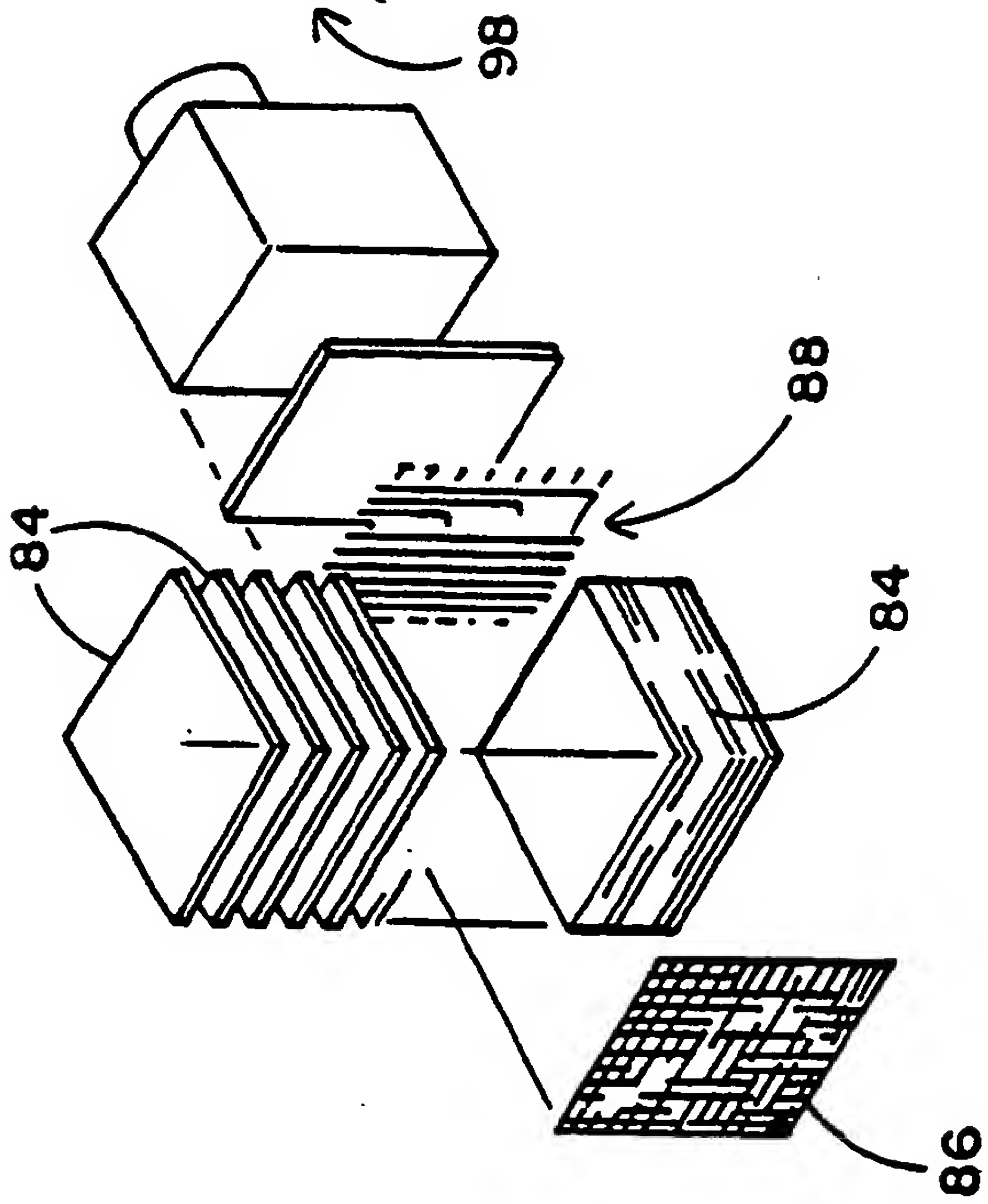
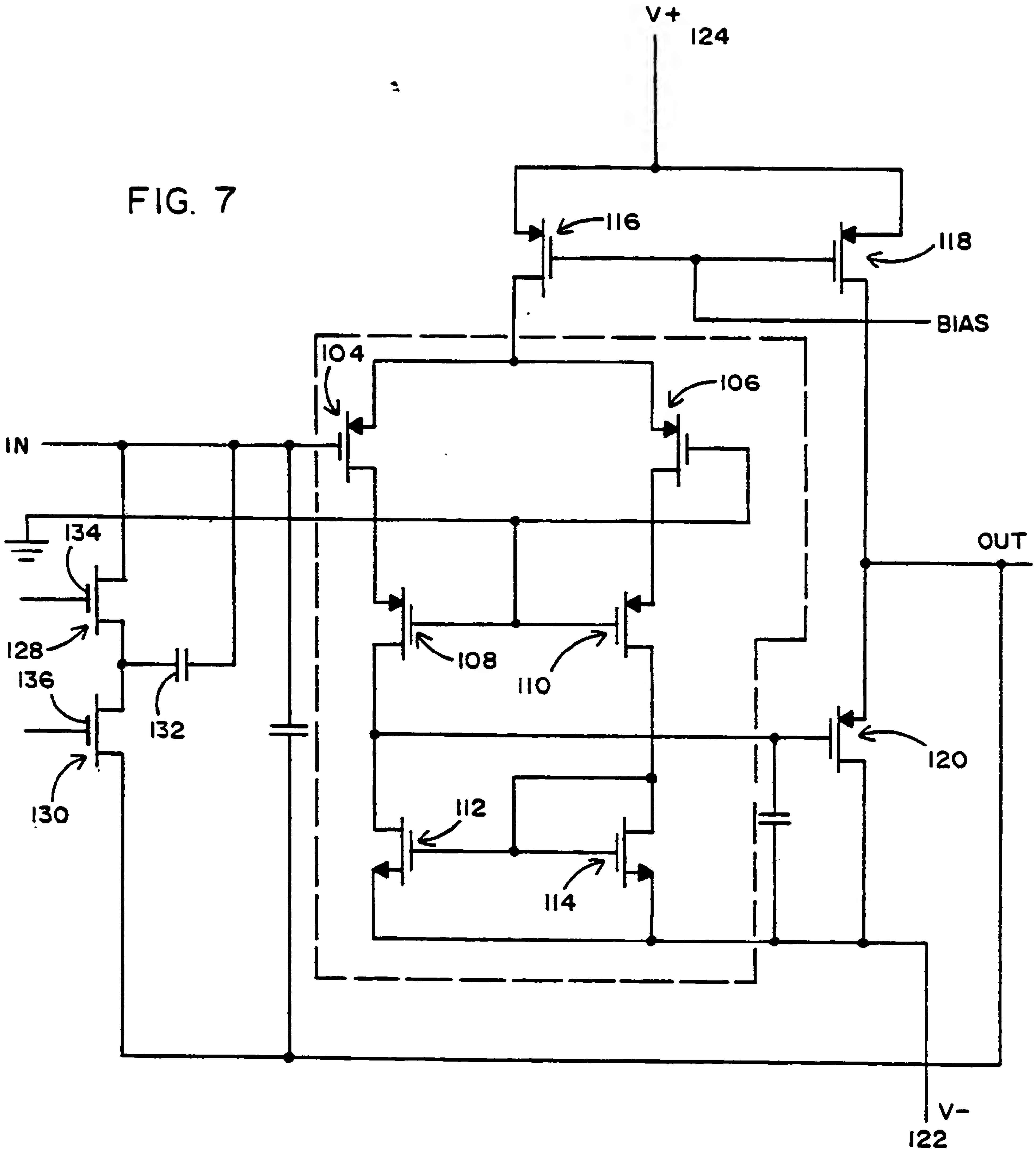


FIG. 5

FIG. 7


V+
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V-
122

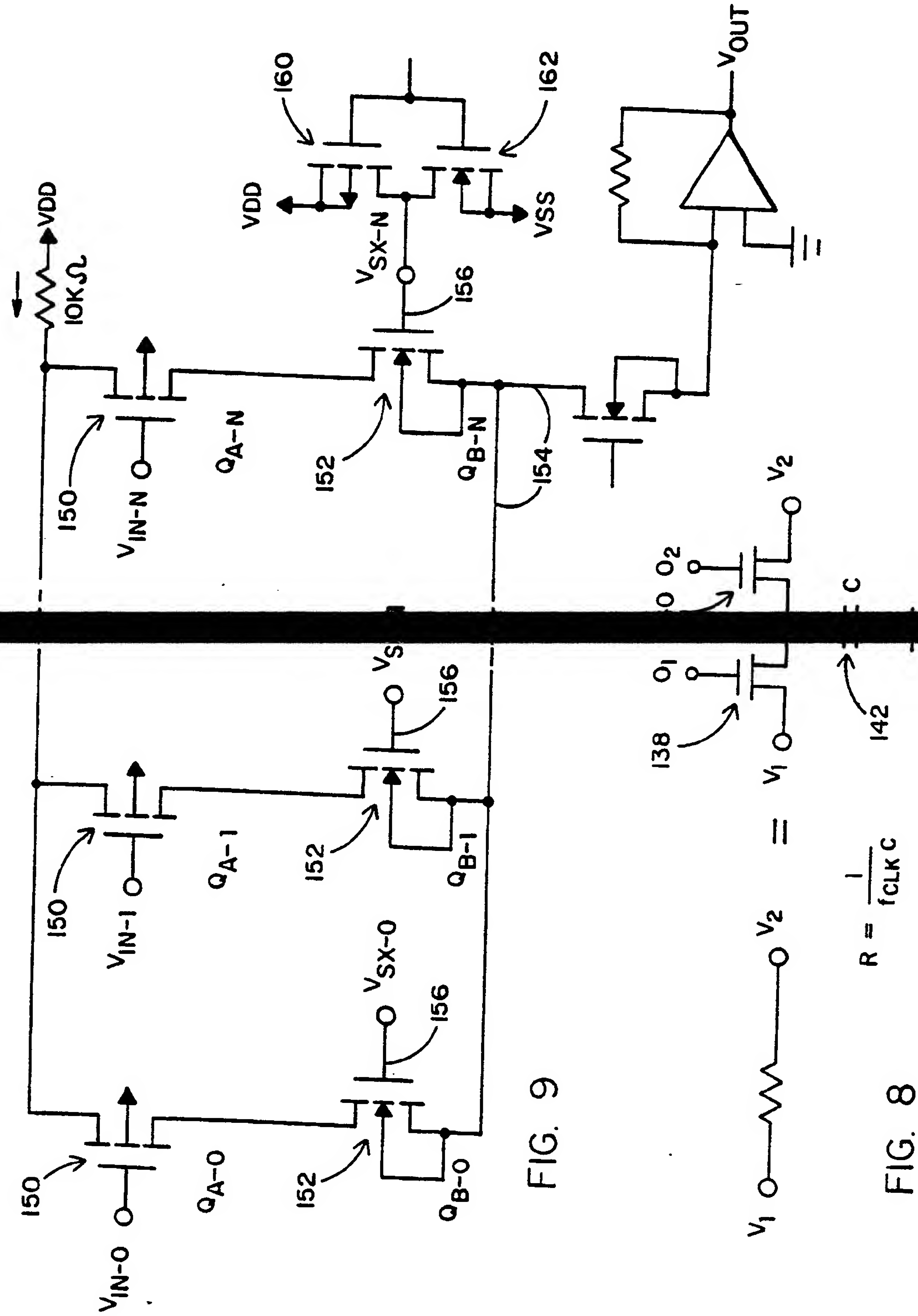

FIG. 9

FIG. 8

SUBSTITUTE SHEET

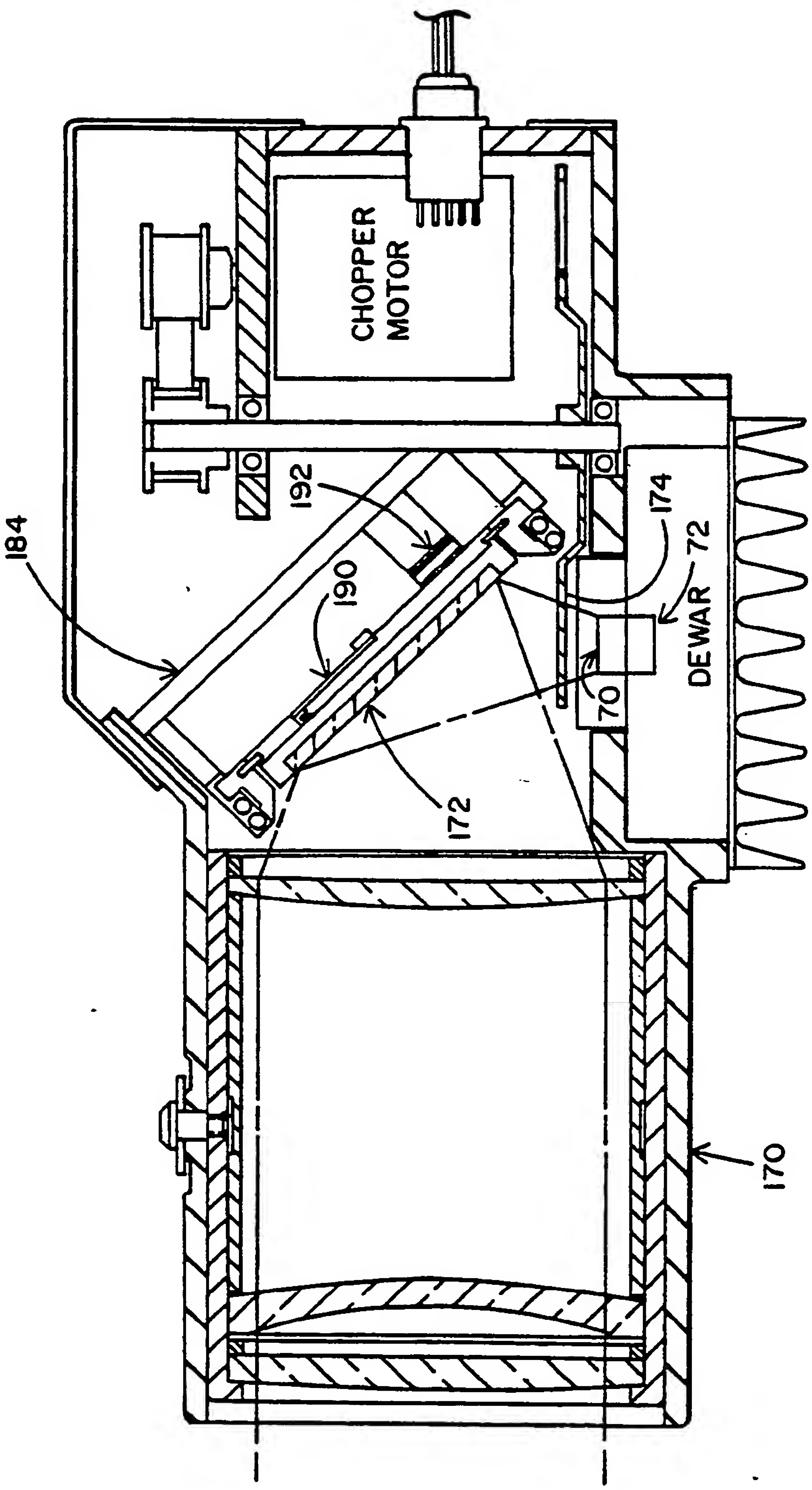

FIG. 10

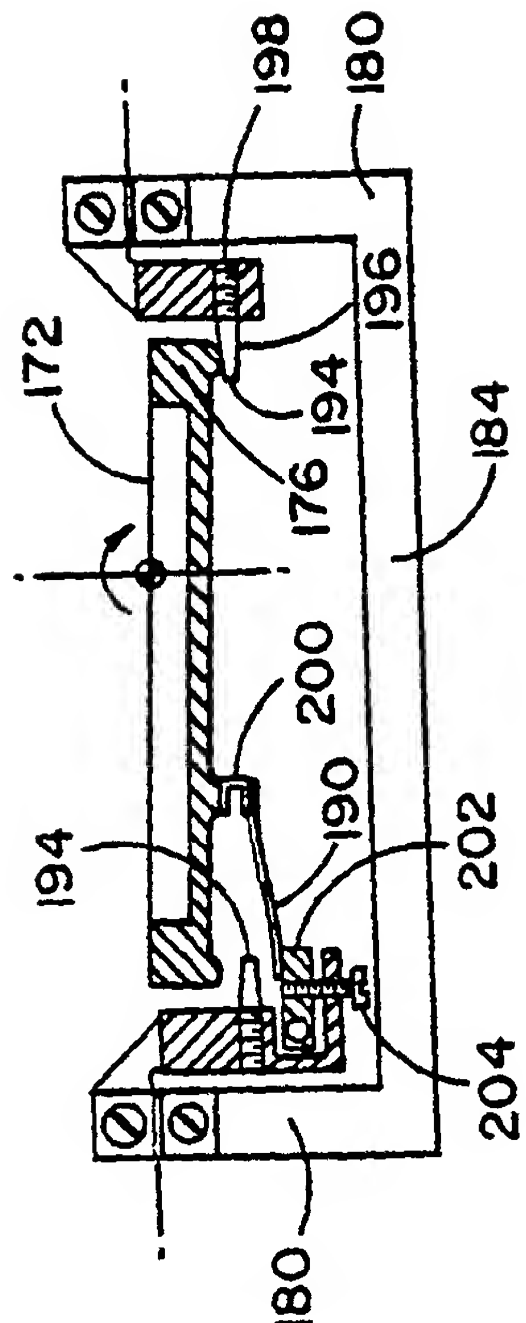

FIG. 12a

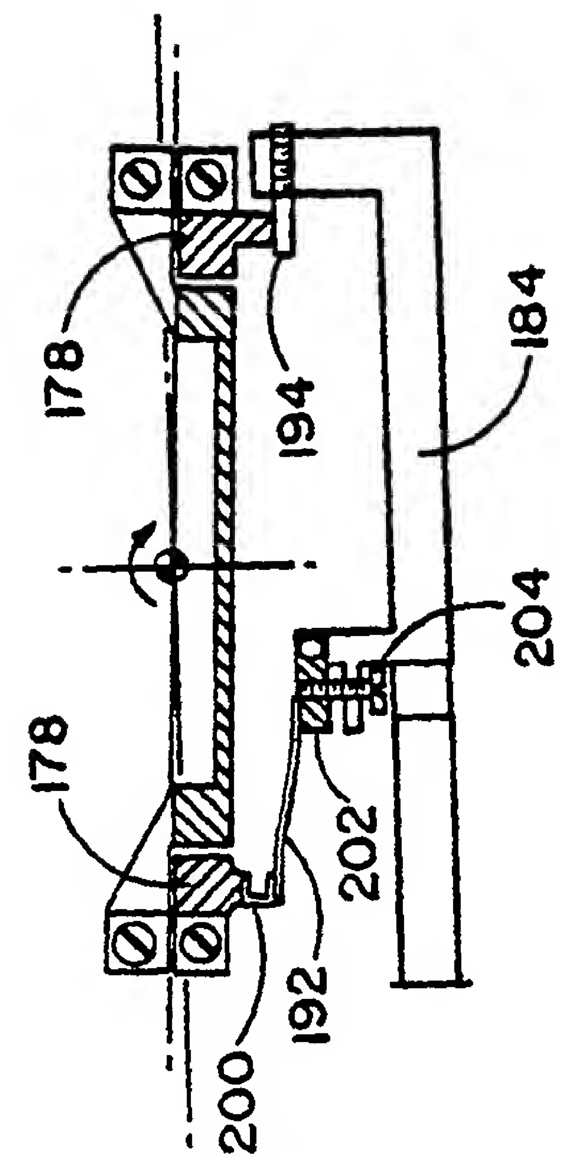

FIG. 12b

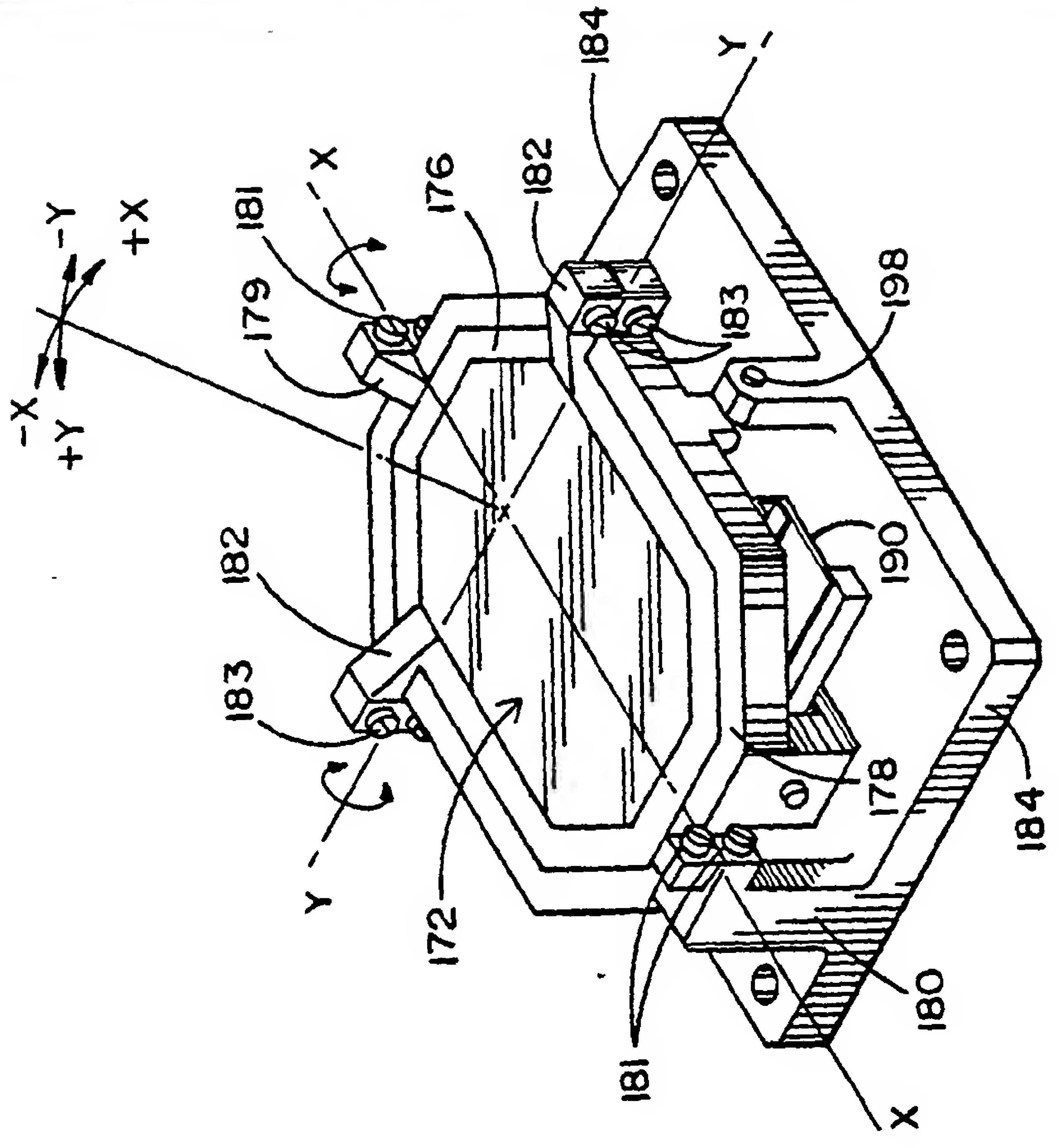

FIG. 11

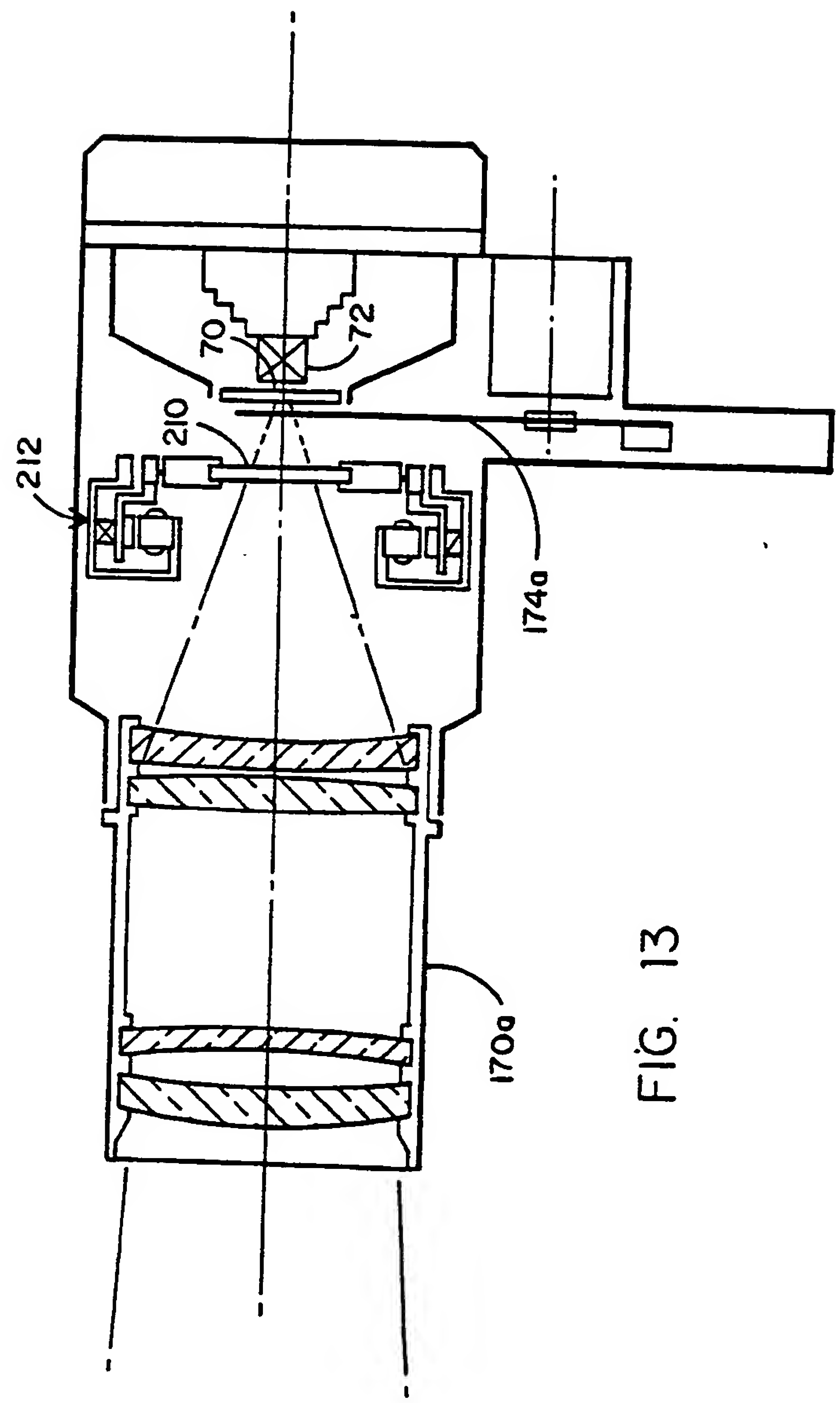

FIG. 13

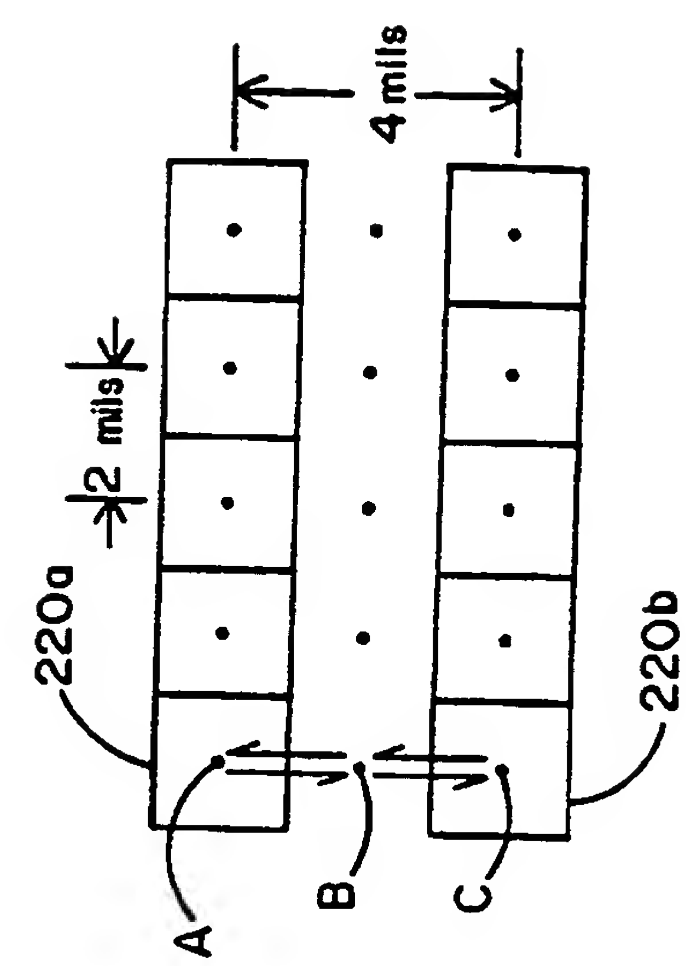

FIG. 15

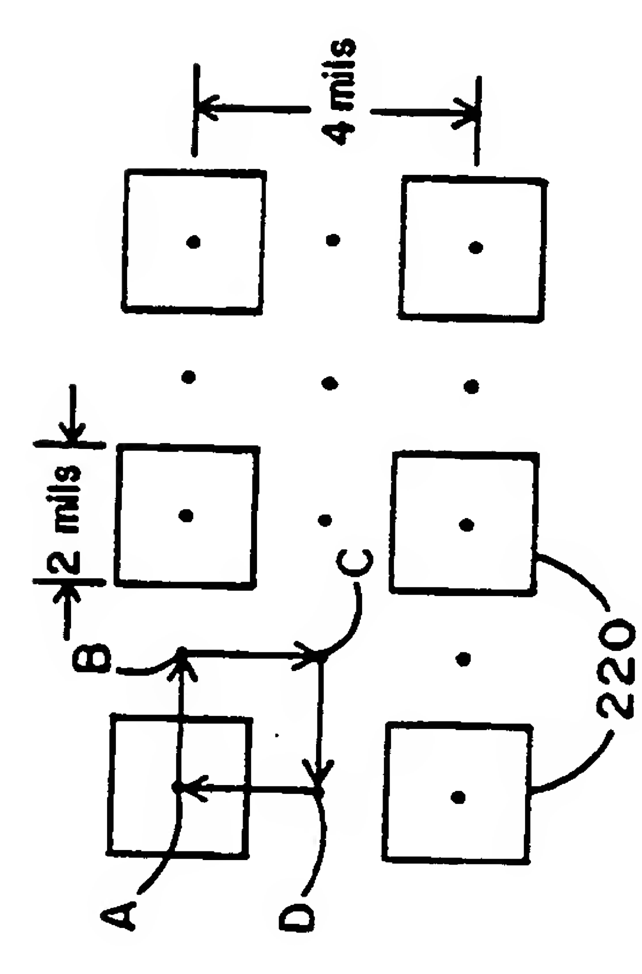

FIG. 14

INTERNATIONAL SEARCH REPORT

International Application No PCT/US86/00688

I. CLASSIFICATI N F SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(4): H01L 27/14, 31/00; G02B 26/10

U.S. CL. 250/332, 370G, 334

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	250/332, 370G, 334

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	D. Carlson et al, "Development of a Staring Mosaic Module", SPIE Vol. 197 (1979) Proc. Soc. Photo-Opt. Instr. Ang. (USA), See Figs. 1 and 3	1-10, 11-15
Y,P	US,A, 4,551,629 (Carson et al), 05 November 1985, See figs. 2, 4, 5.	1-10, 11-15
Y,P	US,A, 4,555,623 (Bridgewater et al), 26 November 1985, See column 4.	1-10, 11-15
Y	US,A 4,403,148 (Coon et al), 06 September 1983, See fig. 1.	11-15
A	US,A, 3,808,435 (Bate et al), 30 30 April 1974, See fig 1.	1-10
A	US,A, 3,869,212 (Burcher et al), 04 March 1975, See fig. 2.	11-15

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
18 July 1986	13 AUG 1986
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	Richard Hanig Richard Hanig

Form PCT/ISA/210 (second sheet) (October 1981)